LED Lighting: A Practical Overview

DOE Project Management Workshop

March 15, 2011

Dr. John W. Curran, President, LED Transformations, LLC

On behalf of the U.S. Department of Energy



LEARNING OBJECTIVES

LED LIGHTING: A PRACTICAL OVERVIEW

1. Critical differences between SSL and other lighting technologies

2. Understanding the effect of thermal management on product lifetime

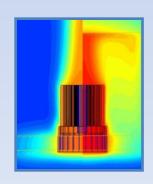
3. How to distinguish good from poor SSL products and applications

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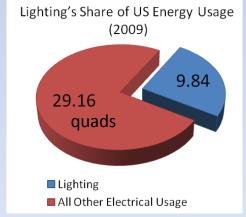
COURSE OUTLINE

- 1. Introduction Why should I care about LEDs?
- 2. What's different LED technology as compared to traditional light sources
- 3. Technology Limitations Characteristics to be aware of with solid-state lighting
- 4. LED Products Where to turn for guidance
- 5. Applications What are the good ones?
- 6. Final Thoughts Some general rules



Why Should I Care About LEDs?

- By 2030 the US Department of Energy has estimated that LED technology has the potential to produce yearly energy savings of 190 terawatt-hours
 - Equivalent of 24 large (1,000 MW) power plants
 - Reduction of 25% of present energy consumption for lighting
 - Equates to approximately \$15 billion savings in today's dollars
 - Greenhouse gas emissions reduced by 31.4 million metric tons of carbon
- Spanning 2010 2030, the cumulative energy savings are estimated to total approximately 1,488 terawatt-hours
 - Representing approximately \$120 billion at today's energy prices
 - Over that same time period, greenhouse gas emissions would be reduced by 246 million metric tons



Data Source: DOE 2010 SSL R&D MYPP

Source: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl energy-savings-report 10-30.pdf

What have you heard about LEDs?

- They don't produce any heat
- They last forever
- Anyone who isn't installing LED-based products everywhere is foolish
- There is a conspiracy to limit the use of LEDs
- There is a conspiracy to force the use of LEDs
- They don't work
- They are too expensive

What is the truth about LEDs?

- They do produce heat just not as much
- They don't last forever just longer than other sources
- Anyone who isn't considering installing LED-based products for some applications is foolish
- They don't work if misapplied
- They are expensive but costs continue to drop
- There is a conspiracy by physicists to force the metric system on everyone having nothing to do with LEDs

Why Should I Care About LEDs?

LEDs are like no other conventional lighting source

- + Potentially longest¹ life of any lighting sources
- Very high energy efficiency
- Small size and instant on allows new applications
- + Produces color light directly without filtering
- Integrates well with other semiconductor electronic elements
- Thermal management requirements
- Cost
- New technology brings unfamiliar issues to architects, lighting designers, building owners and facilities managers

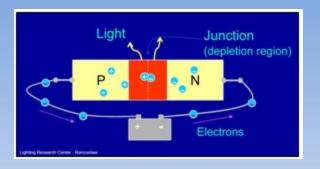
¹Note: Some manufacturers have introduced products claiming long lifetimes: fluorescent tubes (40,000 hours); induction (100,000 hours)



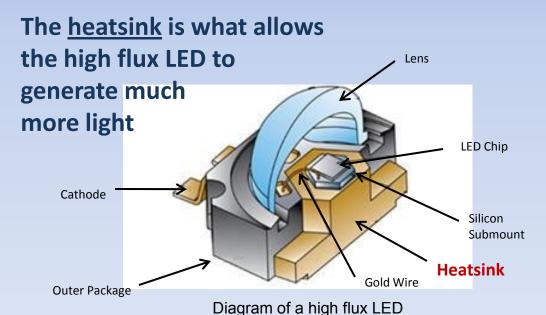




What is an LED?



An LED (Light Emitting Diode) consists of a chip of semiconducting material treated to create a structure called a p-n (positive-negative) junction



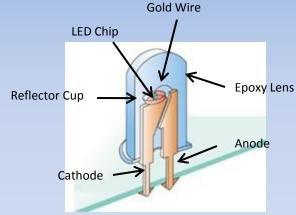
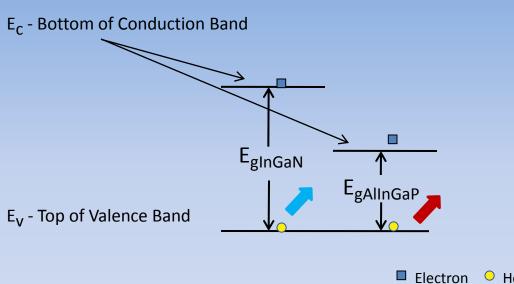
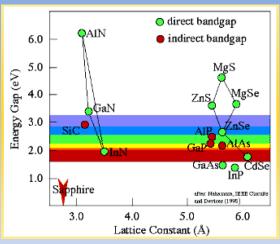


Diagram of a 5mm LED

How does the LED make light?

Bandgaps – Different gaps, different colors



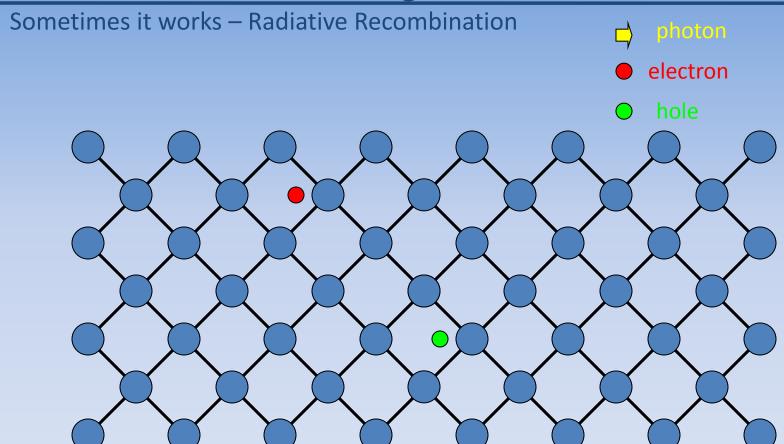


Source: Ian Ferguson, NC University

Smaller bandgap → Lower energy → Longer wavelength photon → Red Larger bandgap → Higher energy → Shorter wavelength photon → Blue

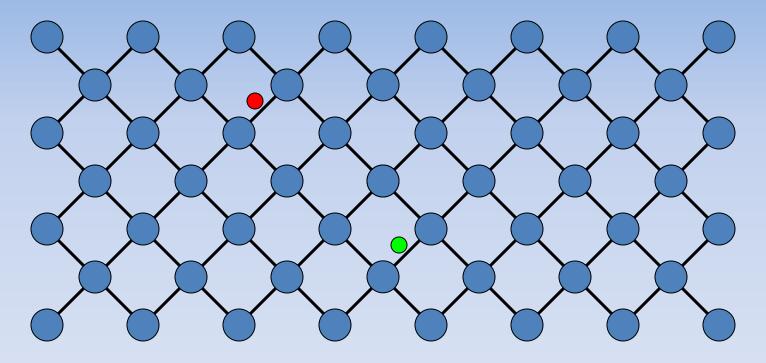
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How does the LED make light?



How does the LED make light?

Sometimes it doesn't - Non-radiative Recombination

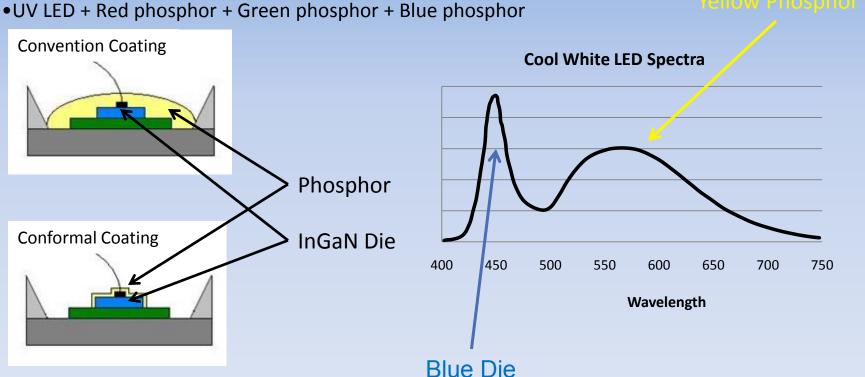


Creates heat instead of light

How does a white LED work?

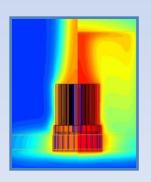
Downconverting Phosphor

- •Blue LED + YAG (Yttrium aluminium garnet) Cool White
- •Blue LED + YAG + Other phosphor (red, green, etc.) Warm White



COURSE OUTLINE

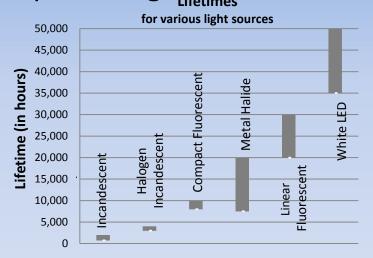
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Long Lifetimes

 Traditional light sources fail catastrophically due to electrodes which weaken or become contaminated and eventually fail, causing the lamp to stop working

- LEDs rarely fail catastrophically
 - Light output gradually decreases over operating time
 - End of life defined to be when light output reaches 70% of initial value



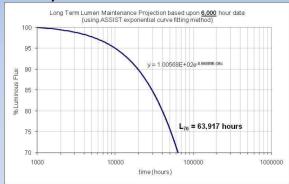
- Raises issue for designers how to warn users that product has exceeded end-of-life and is producing less light than the application may require
- Lifetime highly dependent on temperature (ambient and device as well as operating current

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Long Lifetimes – A Measurement Issue

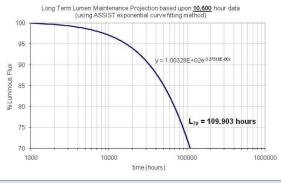
 It is difficult to predict the long term performance of a device with only early lifetime data

6,000 Hours of data



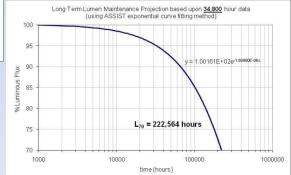
Source: Cree

10,600 Hours of data

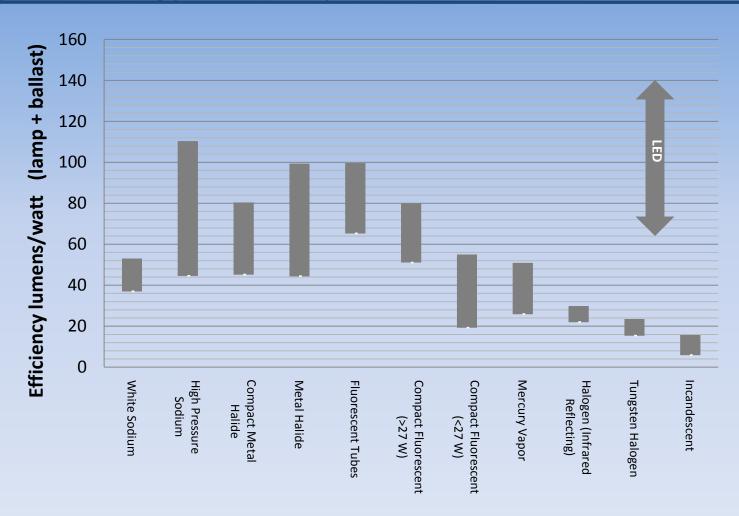


Almost 3.5 X's longer predicted lifetime than the 6,000 hour results

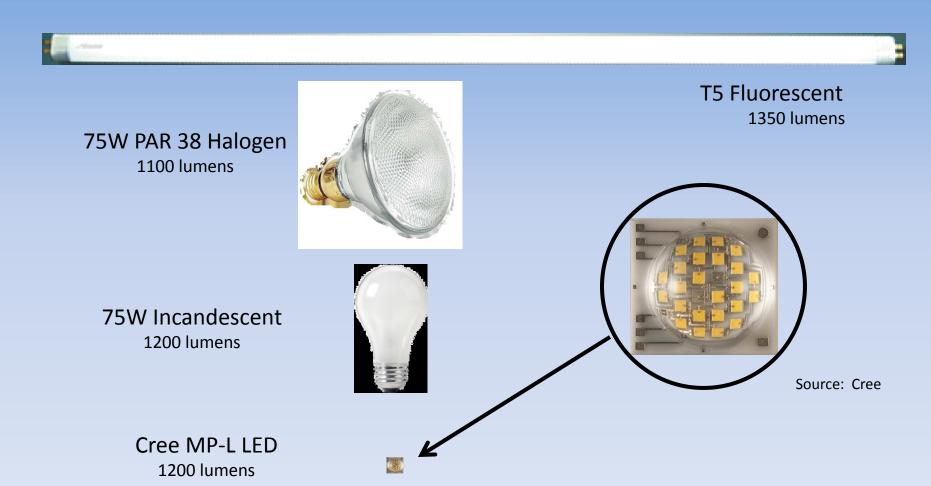
34,800 Hours of data



Highest Energy Efficiency

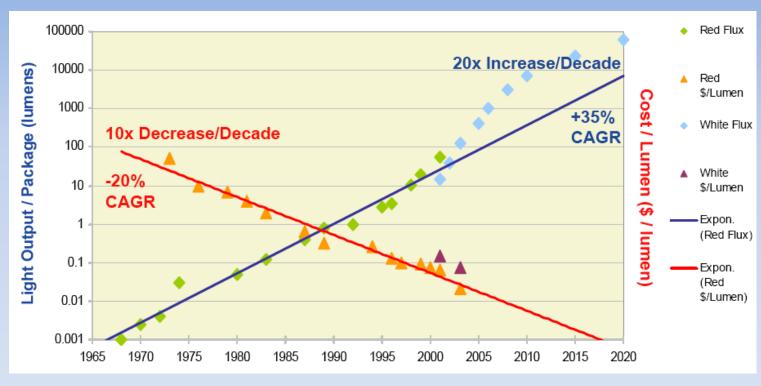


Small Size



Rate of Development

LEDs follow a development rule known as Haitz's Law



Source: Roland Haitz & Lumileds

New Names and Shapes in Lighting

Traditional Lamp Suppliers

Sylvania



Philips



• **GE**



LED Suppliers

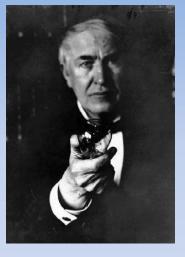
- Osram
- Lumileds
- Cree
- Bridgelux
- Nichia
- Seoul Semiconductor
- Toshiba
- Sharp
- Toyota Gosei
- Edison Opto
- and many more...



Obsolescence — Part of the economic picture

• If Edison were alive today, he would certainly recognize his

light bulb



 If you owned this fixture, you could still get lamps for it



light fixture

Source: Scot Hinson, Modeliving

Obsolescence — Some things don't change

A 1942 Magazine ad for General Electric fluorescent lamps

A 2007 news release from a lighting magazine on an improved fluorescent lamp

Philips Lighting introduces revolutionary new Alto II linear fluorescent lamp technology

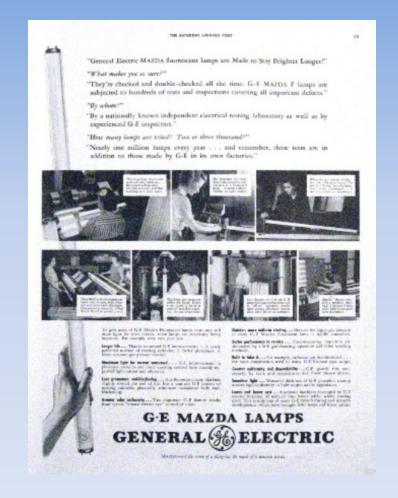
Date Announced: 06 Sep 2007

SOMERSET, N.J. - Philips Lighting Company, a division of Philips Electronics North America Corporation, an affiliate of Royal Philips Electronics (NYSE: PHG, AEX: PHI), proudly announces the introduction of ALTO II, its next-generation low-mercury fluorescent lamp technology for the professional lighting market.

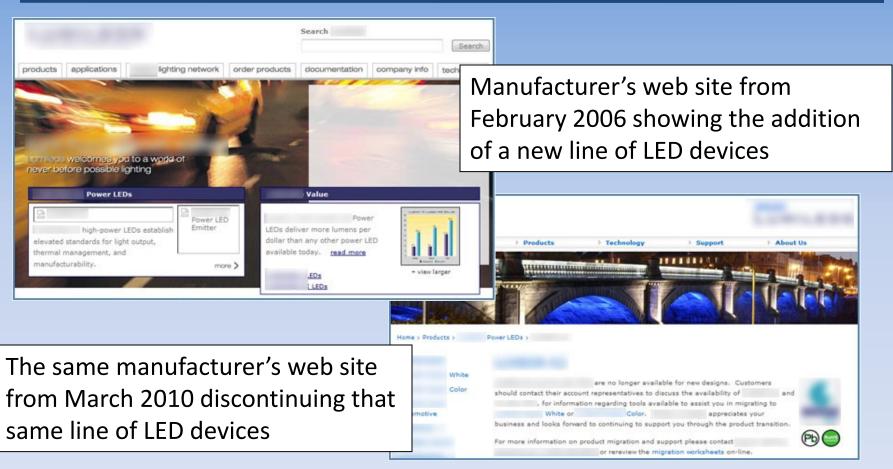
Twelve years ago, Philips Lighting introduced its original ALTO technology and set a new industry standard by reducing the amount of mercury in its T8 fluorescent lamps to an industry low of 3.5 mg.

Today, through Philips Lighting's innovative technology, ALTO II T8 lamps now contain only 1.7 mg of mercury, an unprecedented 50 percent reduction from previous levels.

Now incorporated into a variety of 32-Watt Philips T8 lamps, lamps with ALTO II technology will continue to deliver the same high performance as the previous generation of ALTO lamps.



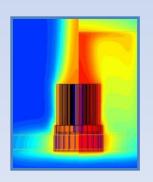
Obsolescence — And some things do



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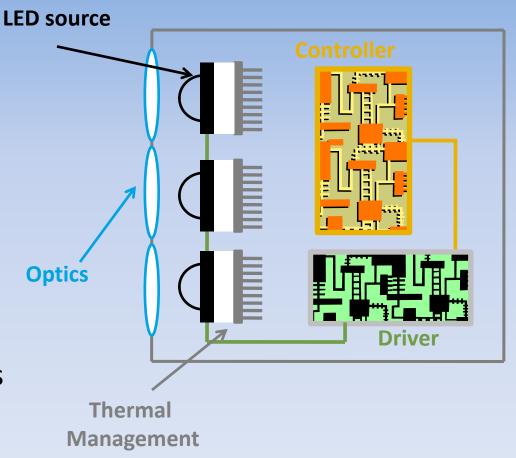
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Luminaire Lifetime — A Luminaire is a System

The failure of any one component can cause the entire system to stop functioning

Luminaire designers make trade-offs among the components, depending on the desired performance criteria – for example the number of LEDs (\$\$\$) versus drive current (lifetime)

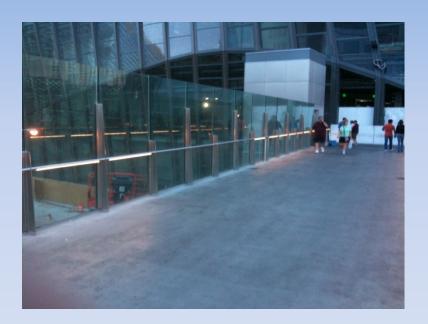


Luminaire Lifetime — A Luminaire is a System

Two examples of failures caused by the driver



NJ Supermarket Freezer Case



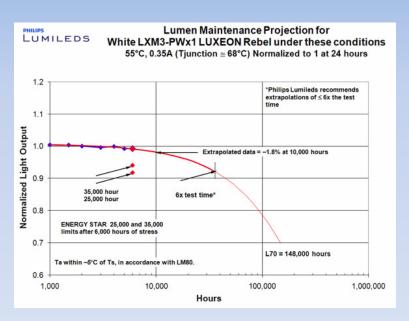
City Center, Las Vegas

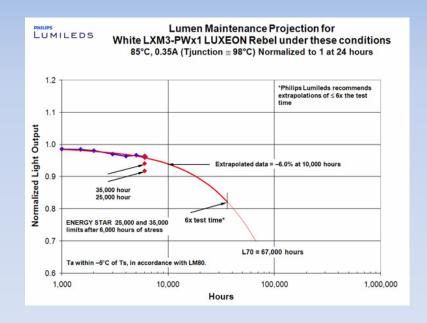
Source: LFD Transformations

Effect of Heat on Lifetime

LED Lifetime with ambient temperature of 55°c is 148,000 hours

LED Lifetime with ambient temperature of 85°c is 67,000 hours



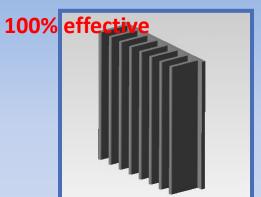


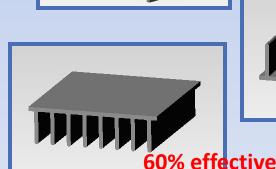
Source: Lumileds

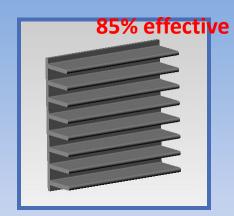
Luminaire Orientation Can Effect Lifetime

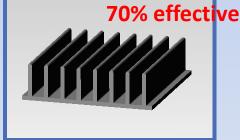
Luminaire manufacturers must take desired orientations into account when designing thermal management system for products

LM-79 testing standard requires the luminaire be tested in the orientation in which it will be mounted









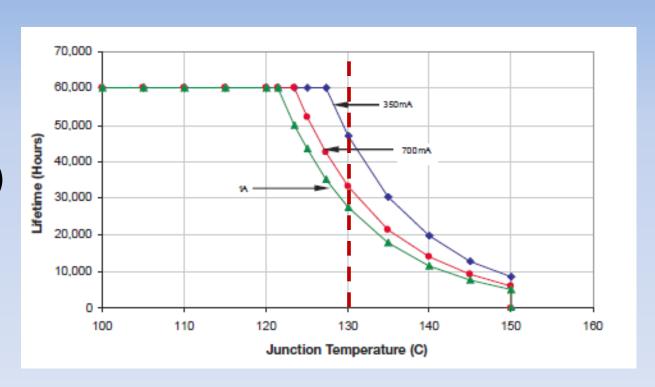
Effect of Drive Current on Lifetime

At a junction temperature of 130°C lifetime is

28k hours (1 A)

33k hours (0.75A)

48k hours (0.350A)



Source: Lumileds Data Sheet

Color Matching / Color Shift

Supplier quality and testing is critical to successful projects

White is white?

Is blue?



Initial

84.1%
Drop

97.8%
Drop

96.9%
Drop

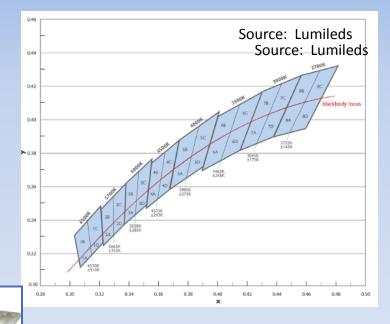
Source: Cree

Color Binning

Solid-state lighting manufacturers cannot control the exact color characteristics of LEDs when they are fabricated. To compensate they sort the finished LEDs into color bins.

Customers purchasing the widest range of bins get the lowest prices. It then becomes their responsibility to produce consistent color products.

At least one manufacturer with a multi-chip product is mix and matching within the device to provide consistent color.



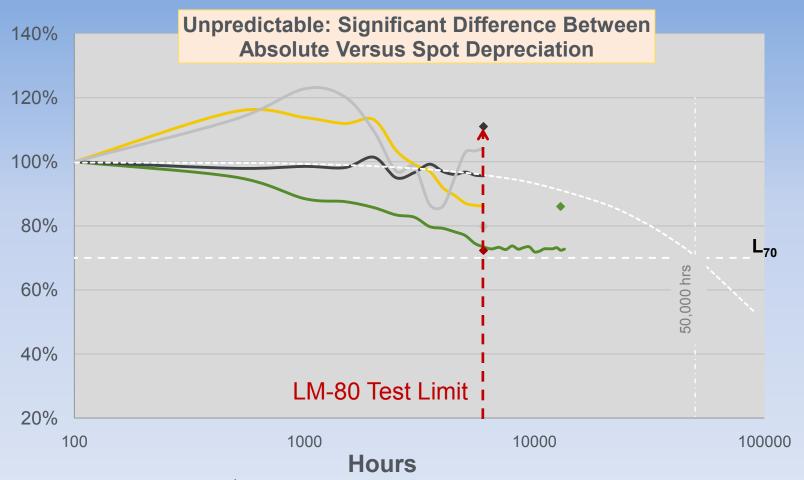
Source: Cree

Standards

- LM-79-08 Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products
 - Describes testing procedure for evaluating light distribution from LED-based luminaires
- LM-80-08 Approved Method for Measuring Lumen Depreciation of LED Light Sources
 - Describes testing procedure for measuring lumen depreciation of LED devices
 - Does not describe how to evaluate data taken
- No approved standard available for driver lifetimes



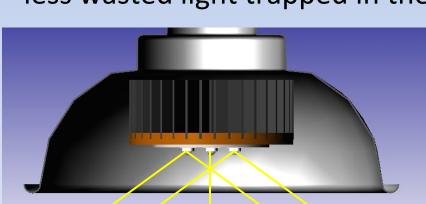
Lifetime — Initial Depreciation Results Can Vary Greatly

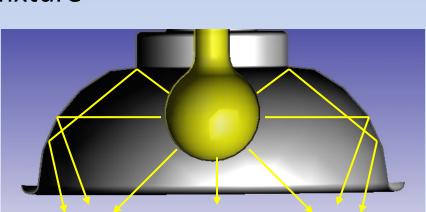


CALiPER Round 10 data, www.ssl.energy.gov/caliper.html

LED Light Output — "Equivalent" to conventional sources?

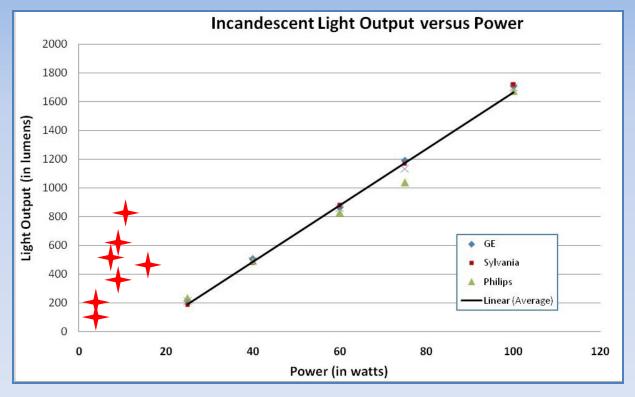
- LED devices have highly directional light output unlike conventional light sources
- In directional fixtures such as downlights, this results in much less wasted light trapped in the fixture





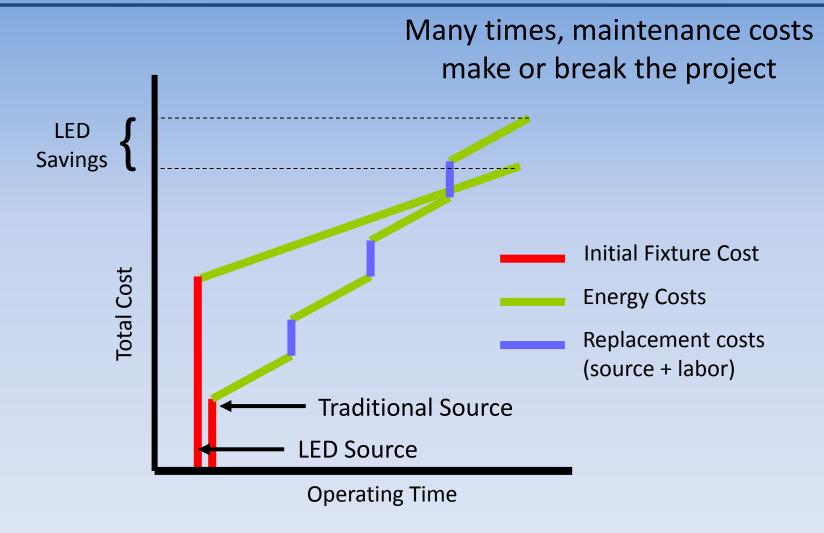
The Word "Equivalent"

Incandescent lamp light output can be accurately conveyed by listing the lamp's power (wattage) LED-based lamps do not show the same linear relationship due to the differences in device efficacy



Source: LED Transformations

LED Economics



TECHNOLOGY LIMITATIONS

Dimming

- Because LED systems work differently from those of incandescent lamps, dimming is often an issue
- LED drivers must be designed to be compatible with line-voltage dimmers (of which there are many types)

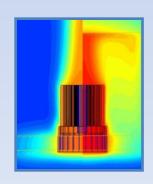


- Many line-voltage products not compatible (like CFLs)
 with certain dimmers
- Many low voltage LED systems with certain stepdown transformers are not compatible with certain dimmers
- One dimmer manufacturer provides a matrix showing compatibility and functionality with various manufacturers' luminaires/or drivers

Manufacturer	Model	Description	Dimming Range*	Compatible Product?
	Hi-lume LED driver	Driver	100% -1%	YES.
	Xitanium	Current Driver	Not Specified	YES
	Xitanium	PWM Driver	100% - Off	YES
-	eW PowerCore	Strip Light	100% - 15%	YES.
	eW Profile : 11"	Under Cabinet Light	100% - 15%	YES
	eW Profile : 41"	Under Cabinet Light	100% - 15%	YES
-	eW Downlight	Downlight	100% -15%	YES
	Downlight	6" Downlight	100% - 5%	YES
	LR4	4" Downlight	100% - 20%	YES
	LR6	6" Downlight	100% - 20%	YES
100	LR6 - 230V	6" Downlight	100% - 20%	YES
1000	LR24	24" x 24"	100% - 5%	YES
	Tetra dimming module	Driver	Not Specified	YES
f	LED Cove Light	Cove Light	100% - 3%	YES
	Downlight	Downlight	Not Specified	YES
giller	LED-18-350-120-D	Driver	100% - 0.1%	YES
grant .	LED-36-700-120-D	Driver	100% - 0.1%	YES
girote.	Calculite 10W	Downlight	N/A	YES
-	Calculite 20W	Downlight	N/A	YES
100	Par 30	Par 30 lamp	Not Specified	YES
-	OT Dim	Driver	100% - Off	YES

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LED PRODUCTS

One Way to Determine What's Good - CALIPER

Results from Round 9 CALIPER testing (October 2009) show that a large number of LED replacement lamp product manufacturers are still not providing accurate performance data

Table 4. C	ALiPER ROUND 9 – Rep	lacement Lamp Manu	facturer Claim	s
Sample Type and CALiPER Reference	Manufacturer Claims	Actual Performance Level (e.g. Light Output, Efficacy, CBCP, Beam Angle)	Provides Accurate Product Reporting	
Replacement Lamp (MR16) 09-80	180 lm, (54-69 lm/W) Eq. to 35W halogen	165 lm, 50 lm/W 304 cd, 31° Less than average 20W halogen	NO	
Replacement Lamp (R20) 09-78	230 lm, (32 lm/W) 7W=35W	263 lm, 42 lm/W 944 cd, 25° Exceeds average 35W halogen	YES	
Replacement Lamp (R30) 09-64	Replaces 45W (450 lm, 128 lm/W) CRI=84, 30° beam	186 lm, 54 lm/W CRI=71, 695 cd, 20° Less than 20W eq.	NO	r
Replacement Lamp (PAR30) 09-76	Eq. to 75W Incand. 550 lm, 70 lm/W 60-70° beam	468 lm, 59 lm/W 190 cd, 100° Eq. to 50W R30	NO	
Replacement Lamp (PAR38) 09-63	Replaces 45W (450 lm, 90 lm/W)	289 lm, 58 lm/W 902 cd, 22° Less than 25W eq.	NO	
Replacement Lamp (A-lamp) 09-60	260 lm, (34.6 lm/W) Replaces 40W incandescent	251 lm, 34 lm/W Eq. to 25W incandescent	NO	
Replacement Lamp (A-lamp) 09-77	155 lm, (22 lm/W) Eq. to 25W	208 lm, 33 lm/W Eq. to 25W incandescent	YES	(In
Replacement Lamp (Candelabra) 09-65	Replaces 40W (320 lm, 220 lm/W)	67 lm, 45 lm/W Less than average 15W incandescent	NO	
Replacement Lamp (Candelabra) 09-74	30 lm, (12 lm/W) "Uses less energy than	31 lm, 17 lm/W Eq. to 7-15W night	YES (possibly	1

CALIPER results are available at:

http://www1.eere.energy.gov/buildings/ssl/caliper.html

LED PRODUCTS

Another Way — Lighting Facts Labels

Don't trust a single data sheet without backup

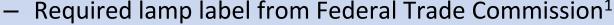
- IES files match shipped product performance
 - If data is based on a "one of a kind" sample, lighting performance will

most likely be deficient when facility is completed

- Lighting Facts™ Labels
 - Provide assurance that product will perform as specified

for luminaires

DOE Label



- Optional label from Dept. of Energy
- LM-79 luminaire third party test data
 - Acts as a double check even for high quality luminaire manufacturers

¹FTC Labeling takes effect mid-2011



Lighting Facts Per Bulb

Brightness 820 lumens
Estimated Yearly Energy Cost \$7.23
Based on 3 hrs/day, 11¢/k/Wh
Cost depends on rates and use
Life
Based on 3 hrs/day 1.4 years
Light Appearance
Warm Cool
2700 K
Energy Used 60 watts

lighting facts

for lamps (front/back)



Energy Star — SSL Luminaires General Requirements

Highlights of Luminaire Criteria (V1.0)

- Energy Star is a voluntary criteria
- Indoor luminaires shall have a minimum CRI of R_a>80 (Was R_a>75)
- Requires zero off-state power draw for the fixture; if controlled then < 1W
- Lumen Maintenance:
 - Residential 25k hrs Indoor, 35k hrs Outdoor
 - Commercial 35k hrs commercial

PF > 0.5 not previous included

(Was < 0.5W)

- Power Factor: Products drawing less than/equal to 5W require PF > 0.5;
 Products drawing > 5W require PF > 0.7 (residential), PF > 0.9 (commercial)
- ENERGY STAR qualification is not automatically granted for the life of a product model
- CCT shall be within one of the following groups: 2700K, 3000K, 3500K, 4000K, 5000K (commercial only) and within the ANSI C78-377-2008 chromaticity quadrangles (Dropped 4500K, 5700K and 6500K)
- EPA is pursuing a technology-neutral criteria. These criteria take effect
 October 1, 2011 Red indicates present SSL Criteria (V1.3)

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LED PRODUCTS

Gateway Program — Demonstrations in Various Applications

Demonstrations showcase high-performance LED products for general illumination in a variety of commercial and residential applications. Results provide real-world experience and data on state-of-the-art solid-state lighting (SSL) product performance

and cost effectiveness.

Downlights Lane City Tour of Homes



Eugene, OR

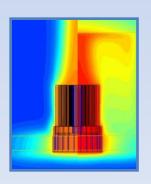






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Downlight - Good



Incandescent 5,135 W

LED 948W

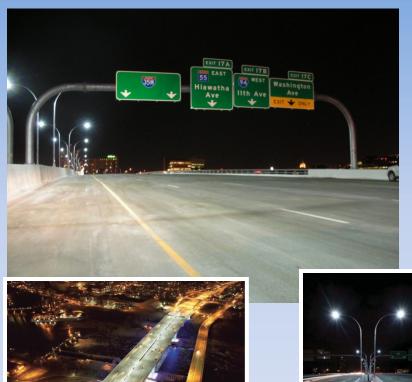
Friendly's Restaurant, Westfield MA

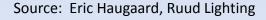
Makes use of directionality

Source Cree

LED (2 Years Later)

Street & Area Lighting — Good







Makes use of directionality





Source: US DOE Gateway program

Source: Lightscape Concepts & Design

Task Lights / Bollards — Good





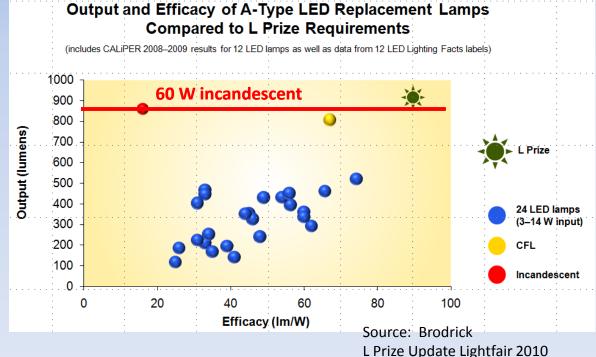
Makes use of directionality and small form factor

Good Ones & Bad Ones - Replacement lamps



Lamp envelope limits the design of the LED system (i.e. heatsinks, optics, total output, etc.) many lamps don't match the incandescent light output of the lamps they are intended to replace











Fluorescent Replacements – Depends

2x4 parabolic louver Fluorescent T8

0.92 LLD

0.95 LDD

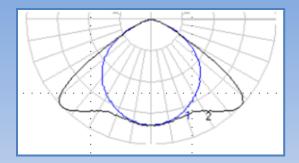
0.88 BF (n/a)

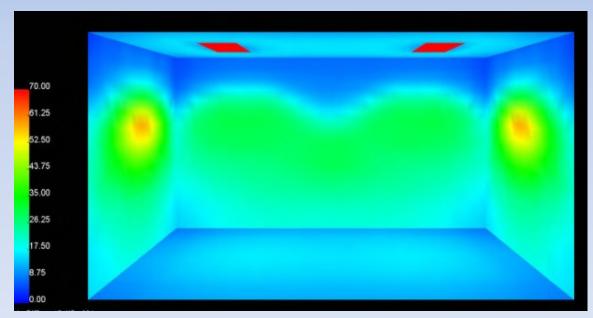
0.65 W/ft²

25 fc (average)

1.9 max/min







Source: Tuenge & Myer, DOE PNNL

Fluorescent Replacements – Depends

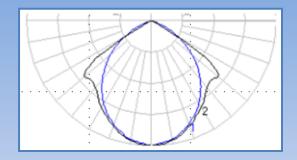
2x4 parabolic louver LED Replacements

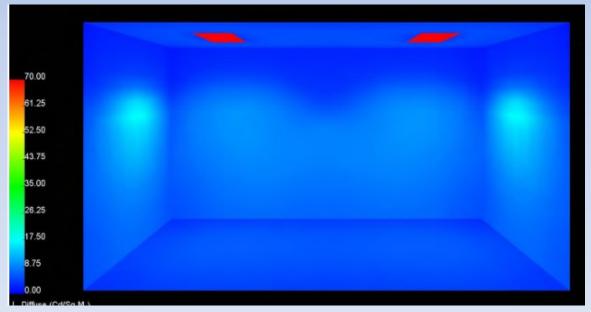
0.70 LLD 0.95 LDD

1.00 BF

0.44 W/ft² 10 fc (average) 2.3 max/min



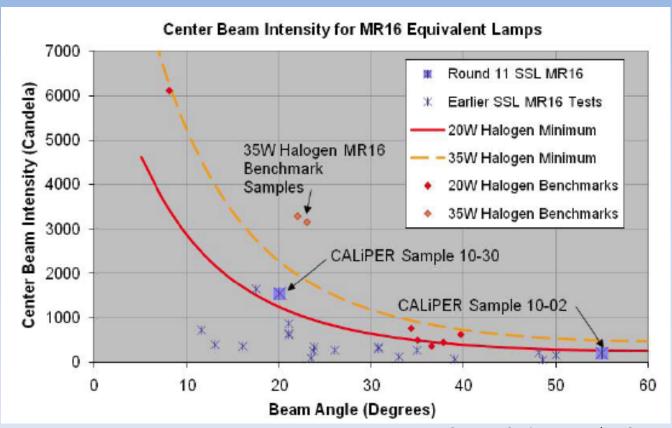




Source: Tuenge & Myer, DOE PNNL

High Power MR-16s — <20W good; > 20W not so good

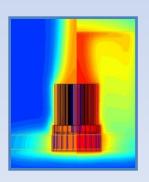
Halogen versus LED-based MR-16 test results



Source: CALiPER Round 11 Summery Report

COURSE OUTLINE

- 1. Introduction Why should I care about LEDs?
- 2. What's different LED technology as compared to traditional light sources
- 3. Technology Limitations Characteristics to be aware of with solid-state lighting
- 4. LED Products Where to turn for guidance
- 5. Applications Good ones and bad ones
- 6. Final Thoughts Some general rules



Items of Importance - Availability

It doesn't save energy if you can't get it

- Lighting is typically ordered late in the construction process. Backorder status because vendor builds in batches or ships quarterly from overseas does not help.
- Importance of spares when things do break or fail
 - As more LED-based products become available, this should be less of an issue
- Availability 5 years from now

Quantity	Catalog Number	Description		Ship Status	Ur	nit Price	Total
5	DL - 2700-6-120	LED Downlight (2700K), 6" 120VAC		BACKORDERED		\$119.95	\$599.75
15	DL - 3000-8-120	LED Downlight (3000K), 8" 120VAC		BACKORDERED		\$139.95	\$2,099.25
50	CL - 3000-1-24	LED Cove Light (3000K), 1', 24VDC		BACKORDERED		\$45.00	\$2,250.00
10	WW - 3500-5-120	Wall Wash (3500K), 120VAC		BACKORDERED		\$279.00	\$2,790.00
15	DL - 3000-6-120	LED Downlight (3000K), 8" 120VAC		BACKORDERED		\$139.00	\$2,085.00
							\$0.00
							\$0.00
Total for this order						\$9,824.00	

Items of Importance - cost

A few mark-ups along the way

- ROI dependent of end user cost
 - Distribution chain markups can have a major effect on cost to building owners, particularly for higher cost LED-based products



- Utility rebates can make a major difference in ROI
 - Some utilities reluctant to provide rebates due to uncertainty in expected lifetime and luminaire efficiency performance
 - Energy Star ratings provide some assurance to utilities
 - Other review bodies such as Design Lights Consortium

Questions End Users Should Ask

1. Temperature range specification for operation How does that compare with the maximum junction temperature for the LEDs used in the product?

2. Luminaire manufacturer

- How long has the manufacturer been in business? What business?
- Does the firm use brand name LEDs?
- Were the LEDs tested to LM-80?

3. Warranty

- Life expectancy of product (Energy Star requires at least a 3-year warranty)
- What replacement costs are covered (e.g. installation labor, shipping, etc.)
- What performance elements are warranted (e.g. CCT shift, lumen output, luminaire efficiency, etc.)

Questions End Users Should Ask

- 4. Power Issues
 - Power Factor
 - Off-state power consumption (Energy Star requires < 1W)
 - Is the unit dimmable? With what controllers?
 - Step-down transformer compatibility for low-voltage retrofit products
- 5. Does it have a UL / ETL / CSA / applicable safety mark?
- 6. Chromaticity
 - Shift over time/temperature
 - Variation from fixture to fixture
- 7. Luminaire performance
 - Fixture efficiency (in lumens/Watt)
 - Delivered lumens (not just LED device performance)
 - IES files
 - LM-79 test results from approved third party laboratory
 - Lumen maintenance

And an Answer

Do not underestimate the use and practical application of simple COMMON SENSE

- If it seems too good to be true, it probably is
- If you can't understand how a product could do "that," there
 is a high likelihood that it probably "doesn't"
- If nobody else's product does "that" maybe this product does not do it either

Which lamp would perform better?







Where are LED-Based Products Appropriate?

- Outdoor area & street lighting
- Downlighting
- Task lighting
- Display lighting
- Cove lighting
- "Architainment" environments



- Other applications that make use of LED's unique attributes
 - Small size
 - Directionality
 - Low temperature performance
 - Improved secondary optics performance due to die size
- As LED efficacy improves, applications will expand

A Lesson From History

 Think of how the microprocessor has changed the world over the last 30 years.



 The lighting world is about to undergo a change not seen since the invention of the incandescent lamp, and driven by that same semi-conductor industry.

Are you going to be ready for it?

DOE Resources

- SSL Quality Advocates / Lighting Facts^{CM} Label
- CALiPER Program
- Standards Development
- Lighting for Tomorrow
- Technical Information Network

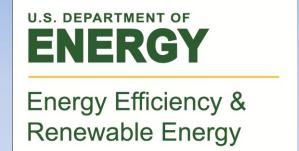
ssl.energy.gov

- GATEWAY Demonstrations
- Next Generation Luminaires[™]
- L-PrizeSM
- Municipal Solid-State Street Lighting Consortium

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Questions?

Thank You

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